REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1979	DRAFT FINAL

4. TITLE AND SUBTITLE

BASIN A NECK AREA, DRAFT FINAL REPORT, RMA CONTAMINATION SURVEY.

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

ROCKY MOUNTAIN ARSENAL
72ND AVE. & QUEBEC ST.
COMMERCE CITY, CO 80022

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

G7900611

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

THE PURPOSE OF THIS REPORT IS TO DOCUMENT THE FINDINGS OF WORK TASKS PERFORMED IN THE BANA (BASIN A NECK AREA) OF THE ROCKY MOUNTAIN ARSENAL. THE RESULTS OF PHYSICAL LABORATORY TESTS ON "UNDISTURBED" SAMPLES ARE INCOMPLETE, AND WILL BE FORWARDED AS AN ADDENDUM TO THIS REPORT. THE PURPOSES OF THE TASKS TO BE ACCOMPLISHED WITHIN THE BANA WERE AS FOLLOWS: 1) QUANTIFY THE GROUND WATER FLOW REGIME AT THE "NECK" OF BASIN A FOR FLOW EXITING BASIN A TO THE NORTHWEST, 2) QUANTIFY THE DISTRIBUTION OF VARIOUS POLLUTANTS IN THE GROUND WATER FLOW SYSTEM EXITING BASIN A TO THE NORTHWEST, 3) IDENTIFY ANY OTHER GROUNDWATER FLOW PATHS (BESIDES THE EXIT FLOW TO THE NORTHWEST LEAVING BASIN A), 4) DETERMINE THE AREAS OF SIGNIFICANT MOVEMENT FOR POLLUTANTS IN THE GROUNDWATER FLOW EXITING BASIN A.

20000501 066

14. SUBJECT TERMS	15. NUMBER OF PAGES
GROUNDWATER FLOW, GEOHYDROLOGIC SURVEY, BASIN A, POLLUTANTS	34
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED			

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TID 1074

BASIN A NECK AREA

DRAFT FINAL REPORT

Rocky Mountain Arsenal Contamination Survey

1. References:

a. DRCPM (now USATHAMA)-DRR letter dated 21 July 1978, with inclosure, Subject: Rocky Mountain Arsenal (RMA) Contamination Survey Plan.

b. DRCPM-DRR letter dated 2 August 1978, with inclosure, Subject: Memorandum of Understanding, Rocky Mountain Arsenal (RMA) Contamination Survey.

c. WESGV letter dated 18 September 1978 with Incl 1, Subject: Basin A Neck Area, Implementation and Test Plan, Rocky Mountain Arsenal (RMA) Contamination Survey.

d. Draft Report, Rocky Mountain Arsenal, Basin A, Groundwater Quality Analysis, by J. R. Kolmer, July 1979.

e. Draft Report, Basin A, Rocky Mountain Arsenal Contamination Survey, by J. D. Broughton, W. O. Miller, and G. B. Mitchell, July 1979.

f. Basin F Containment Hydrogeology Assessment, Rocky Mountain Arsenal, Denver, Colorado, A Report on Results of Deep Drilling Activities, by D. C. Banks, July 1979.

BACKGROUND

2. Reference a contains the Contamination Survey Plan and test rationale for tasks to be undertaken by the U. S. Army Engineer Waterways Experiment Station (WES) in the Basin A Neck Area (BANA) of RMA.

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Reference b contains amplification of the test plan. Reference c contains the Implementation Plan for RMA Contamination Survey tasks to be accomplished in the vicinity of the neck of Basin A and Basins B, C, D, and E at RMA. This work area of RMA has been referred to as the "BANA" since submission of Reference c. The BANA is defined for this report as the area bounded on the southeast by Basin B and cross section line F-F', on the south by a line connecting boring No. 657 with boring No. 639, on the west by a line connecting borings No. 639 through 356, on the north by 9th Avenue between borings 356 and 378, and on the east by a line between borings No. 378 and 130. This area encompasses Basin F as well as Basins B, C, D, and E (see Plate 1).

3. Reference d contains the groundwater sampling strategy and procedures for the study in Appendix A. References e and f each contain background material concerning historical exploratory geohydrological activities at RMA, as well as discussions of the regional geology of the RMA and the area northeast of Denver.

PURPOSE

4. The purposes of the tasks to be accomplished within the BANA were as follows:

- a. Quantify the groundwater flow regime at the "neck" of Basin A for flow exiting Basin A to the northwest.
- b. Quantify the distribution of various pollutants in the groundwater flow system exiting Basin A to the northwest.

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c. Identify any other groundwater flow paths (besides the exit flow to the northwest [in the alluvial aquifer-sic]) leaving Basin A.

d. Determine the areas of significant movement for pollutants in the groundwater flow exiting Basin A.

5. The purpose of this report is to document the findings of work tasks performed by WES in the BANA of the RMA. The results of physical laboratory tests on "undisturbed" samples are incomplete, and will be forwarded as an addendum to this report.

GEOHYDROLOGIC SURVEY

Drilling Activities

6. Prior to the start of this work approximately 150 boring logs were available within the study area. Most of these borings had penetrated only the uppermost, or alluvial aquifer (ALL). However, several borings, most notably 455 on the southeast corner of Basin F, had penetrated two additional aquifers within the "bedrock," or Denver Formation. The upper of these two aquifer units, typically an orange-yellow to green-yellow, fine, slightly silty sand (SM in the Unified Soil Classification System (USCS)), hereinafter is referred to as the Upper Denver Sand (UDS). The lower of these aquifer units, typically a pale-gray to blue-gray, fine, slightly silty sand (SM in the USCS), hereinafter is referred to as the Lower Denver Sand (LDS). In view of these "bedrock" aquifers WES obtained permission to drill BANA exploratory borings to 100 ft or more at the discretion of the Project Geologist.

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Primary emphasis was still to remain with the ALL in the BANA, with time constraints precluding anything but a relatively cursory examination of the bedrock aquifers.

7. Exploratory borings and piezometer placements were accomplished at the original 23 sites outlined in Reference c, plus additional discretionary sites. Plate 1 illustrates the locations of all boring sites in the BANA. Borings accomplished for this task are numbered 801-826 inclusive plus 640, 651, and 455. The total number of sites occupied for drilling operations was 29, with 21 observation wells being installed in the ALL, 15 sealed piezometers being installed in the UDS, and 13 sealed piezometers being installed in the LDS. Points of interconnection (or "windows") of the UDS with the ALL were found at four sites--808, 810, 813, and 824, and at each of these the shallow observation well was screened from the base of the UDS across the ALL contact and several feet higher. Further, "windows" connecting the UDS with the LDS were found at three sites--809, 823, and 825, and at these sites the sealed piezometer is screened from the bottom of the LDS across the UDS contact and several feet higher. Table 1 is a summary of all drilling activities accomplished under BANA tasks.

Field Permeability Tests

8. The most reliable method for determining aquifer permeability is the classical pump test. Time and funding constraints precluded conducting any true pump tests. However, slug tests or falling head tests, as appropriate, were substituted for pump tests. These field

tests are relatively simple to perform, most tests are completed within 20 minutes, and they are usually reproducible. Slug tests were performed four times on the UDS sealed piezometer at site 455 with all four results lying within a 2.2 percent spread. All tests were performed, and data reduced, as described in References e and f.

9. A total of 39 field permeability tests are reported in Table 2, 6 of which overlap with the Basin A study and 4 of which overlap with the deep drilling assessment around Basin F; of the 29 remaining tests, only 6 required Bouwer and Rice assumptions to obtain a type-curve match, indicating unconfined flow conditions at those sites. Nine tests were conducted in the ALL, but due to the extreme desaturation of the ALL, falling head tests were required--type curve matching was poor on these tests, and the permeability values obtained should be considered to be questionable.

Top of the Denver Formation

10. The elevation of the top of the Denver formation was tabulated for approximately 175 boring sites in the BANA, Basin A, and southernmost F-to-North-Boundary areas. These elevations were plotted in plan view, linear interpolation was used, and a map of "bedrock" topography was contoured. This map, Plate 2, has as its most prominent feature a deeply incised stream channel across the neck of Basin A, and trending roughly from east to west toward the west boundary of the arsenal. During periods of high saturated thicknesses in the ALL this map would be less instructive than it is under current low-saturated thickness

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conditions. Plate 2 indicates that under low-saturation conditions in the ALL, alluvial water flow may become controlled by "bedrock" topography, in which case it is difficult to imagine any significant flow from Basin A flowing anywhere but to the west.

11. A second feature of Plate 2 is the less-prominent channel exiting Basin F to the northeast. Most alluvial flow under Basin F, including vertical leakage from Basin F, would be constrained by "bedrock" topography to flow northeast across 9th Avenue before contributing to the F-to-North Boundary flow regime.

Water Level Distributions

12. As mentioned before, the ALL is in a period of very low saturated thickness conditions. Water level surveys were accomplished in early January, late March, and early June, and most readings are relatively consistent over that period. Some wells showed slightly increasing saturated thicknesses (i.e., wells 626-639) but most of the changes over the three surveys showed water level declines of a few tenths of a foot to over 2 ft. Many wells in all three surveys were "dry." In order to be considered as "dry" one of two conditions must be met:

- a. There is no water in the well, in which case the well is quite literally "dry," or
- b. The water level elevation reported from the survey is below the elevation of the top of the Denver formation in which case the well is functionally "dry."

Plate 3 is a map of water level elevations in the alluvial aquifer for 1 June 1979. Linear interpolation was used between data points.

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Saturated thicknesses were examined, the contoured map compared with the "bedrock" topography map, Plate 2, and the "bedrock" topographic control of flow in the ALL became obvious. Areas of "dry" wells are denoted with the pattern; data control is shown with solid dots ( ).

13. The most dominant feature of Plate 3 is the bifurcating pattern of alluvial flow. The steepest ALL flow gradients are to the west, coinciding with the position of the incised channel in Plate 2. The portion of this bifurcating flow which passes under Basin F is probably a minor component of total ALL flow in the BANA. Indeed, with Plate 3 contoured as shown, only flow from Basin A on the extreme northeast side of the "neck" could possibly follow the gradients shown and actually flow under Basin F. The low flow rate from Basin A, only about 0.4 gpm, probably cannot reach the underflow regime around Basin F, under current low ALL flow conditions.

14. Plate 4 is a contour map of water level elevations for the UDS. Data control, as shown by the solid dots, is sparser than for the ALL map, but is still well enough distributed to result in reasonable confidence in the map. Flow paths in the UDS are generally to the northwest, and they are broadly similar in pattern and distribution to the water level contours in the ALL, Plate 3. The general similarity in contour shape between the ALL and the UDS indicates the possibility of hydraulic interconnection between these two aquifers. In most areas the ALL heads range from about 1 ft to as much as 10 ft higher than heads in the UDS. Areas in which the ALL and UDS heads are quite similar are on the northeast side of the neck of Basin A and the southeastern corner of

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Basin F, suggesting "windows" of interconnection in both areas. Boring logs from Basin A (Reference e) confirm a "window" in the neck of Basin A, and boring logs for sites 444, 448, 452, 455, 456, 876, 877, and 883 (these last two are exploratory borings done by Earth Sciences Associates, architectural engineer contractor to Black & Veatch) confirm the presence of a "window" at the southeastern corner of Basin F.

15. Plate 5 is a contour map of water level elevations for the LDS. Data control, as shown by the solid dots, is even sparser than for the UDS. Without additional data control Plate 5 should be used with caution. LDS contours are broadly similar to both the ALL and UDS maps, Plates 3 and 4. However, heads in the LDS are generally from about 5 ft to more than 25 ft lower than heads in the UDS. Areas in which UDS and LDS heads are quite similar (within about 3 ft of each other) are at site 809 where a UDS-LDS "window" is documented by the boring log, and along the southwestern half of line F-F' where a UDS-LDS window has been inferred from boring logs. Contours are also quite similar along the western side of Basin F, suggesting a window in that area, although data control is too sparse to have any confidence in a conclusion based upon that suggestion. Other interesting patterns to note are: (a) the northeasterly flow path in the neck of Basin A, (b) the axis of westerly flow which is apparently located approximately 1000 ft further south in the LDS than in the UDS and is oriented approximately 45 deg southwest from the axis of UDS westerly flow, (c) the virtually perpendicular orientation of UDS versus LDS flow lines in the neck of Basin A, and

(d) heads in the LDS are higher than those in the UDS in the neck of Basin A between section lines F-F' and G-G' (Reference e).

Stratigraphic Sections

16. Plates 6 through 12 present stratigraphic cross sections for section lines F-F', and for lines U-U' through Z-Z', as shown on Plate 1. On each of these plates the heavy line of highest elevation is the topographic profile of the ground surface. The heavy line next lower in elevation is the top of the Denver Formation. The heavy line of lowest elevation divides the upper part of the Denver Formation containing the UDS from the lower part of the Denver Formation containing the LDS. Whether this line represents an erosional unconformity, a redox boundary, a facies boundary, or some other phenomenon is still subject to speculative interpretation. Above this third line there is very little lignite present in the clays, clays usually show evidence of oxidation (small stringers of limonite and hematite) and the UDS is generally yellow to orange-yellow to green-yellow. Below this line lignite is abundant, there is no evidence of oxidation of iron, and the LDS is usually pale-gray to blue-gray. This evidence tends to support the notion that the third heavy line is a redox boundary dividing an oxidized UDS zone from a reduced LDS zone. Positions of all well screens are shown on Plates 6-12 with a horizontal pattern. Inferred correlations are indicated by dashed lines, while correlations from adjacent holes are shown with solid lines. Total depth of penetration is shown by the vertical lines beneath the boring locations indicated with arrows and boring numbers.

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17. Several observations are possible from these section lines.

a. Line F-F'.

(1) The ALL is in direct contact with the UDS between borings No. 723 and 648.

(2) The UDS is inferred to be in direct contact with the LDS between borings 650 and 651.

(3) Only the deep screens at borings No. 651 LDS, 640 UDS, and 723 through 725 are known to have been sealed with grout, leaving the possibility of drilling-induced contamination migration at many of the other screens in the Denver formation.

b. Line U-U'.

(1) A window between ALL and UDS is strongly suggested between borings No. 817 and 818, and redrilling boring No. 139 could help confirm this suggestion. Since the ALL is "dry" in this area, cross contamination is probably not an immediate problem.

c. Line V-V'.

(1) A man-made ALL-UDS window is possible at boring No. 141 where the confining CH (highly plastic clay in the USCS) at the top of "bedrock" is only about 3 ft thick. The exploratory drilling completely penetrated this CH and a gravel-packed trap enters the UDS here.

(2) A natural ALL-UDS window was drilled through at site 813. The inferred dimension of this window is approximately 600 ft along V-V'.

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(3) A UDS-LDS window is possible and inferred between borings No. 815 and 675.

d. Line X-X'.

(1) An ALL-UDS window was drilled through at site 803. Its lateral extent is inferred at approximately 1300 ft in the vicinity of 803. Redrilling site 41 or 42 is suggested.

(2) A UDS-LDS window was drilled through at site 770 (Reference e). Its lateral extent is inferred at about 1000 ft near 770.

e. Line Y-Y'.

(1) An ALL-UDS window was drilled through by all exploratory borings on Y-Y' northeast of site 490. One or two borings between sites 491 and 824 would help to establish the lateral extent of this window. Its inferred extent is approximately 4000 ft along Y-Y'.

(2) The shallow screen at site 455 has a 67-ft trap on the bottom of the screen, and is probably gravel-packed from the ALL all the way into the LDS thereby aggravating contamination cross connections.

f. Line Z-Z'.

(1) There is an ALL-UDS window across most of the southern end of Basin F between borings No. 805 and 456. Its lateral extent is inferred to be about 2200 ft along Z-Z'.

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(2) A small UDS-LDS window is inferred to be between sites 492 and 804, and may be the lateral continuation of the UDS-LDS window drilled at site 809 to the south.

Total Mass Flux Determinations

18. Four section lines were selected to cover mass flux flow components in BANA. These were: line F-F', line Y-Y', line Z-Z', and 9th Avenue across the north side of section 26. Plates 13 through 16 illustrate the saturated thicknesses of aquifer materials, either present or inferred, along each of these lines. Water levels were plotted on each of the appropriate cross sections and the saturated thickness of "coarse-grained" materials was measured. These were plotted as a function of boring location along the section. Cross sectional areas of the saturated aquifer materials were calculated for use in the expression for calculating flux, Equation 1 below:

$$Q = K\, i\, A \qquad (1)$$

where

Q is the total volume flux (gal/day).

K is the measured permeability (gal/day-ft^2).

i is the hydraulic gradient (dimensionless).

A is the cross sectional area (ft^2).

Values of A and K were substituted in the above expression along with appropriate i values as interpolated from Plates 3 through 5.

19. Prior to making these calculations it become apparent that the field permeability determinations in the ALL aquifer of BANA were of

poor quality and should not be used in the determination of total mass fluxes. It was decided to back-calculate a value of K for the ALL from pump test results from well No. 368 just north of 9th Avenue. Plate 16 shows the saturated thickness of ALL at 9th Avenue, a total cross sectional area of 16,840 sq ft. The local gradient from Plate 3 was very low, and averaged roughly 0.0006 ft/ft. The K value from the pump test of boring No. 368 was used, .33 cm/sec (7000 gpd/ft^2). Thus, the computed total volume of water in the ALL passing 9th Avenue away from Basin F is 49.gpm. On the basis of water quality work done on water from well 118 at the northeast corner of Basin F it has been shown that Basin F fluid leaking into the ALL is diluted roughly tenfold. Therefore, it was assumed that 5 gpm were leaking out of Basin F into the ALL. This is a relatively reasonable number since: (a) if one assumes a permeability for the bottom of Basin F of about 10^{-8} cm/sec (0.0002 gal/day-ft^2); (b) assumes a uniform head gradient of about 5 ft/ft driving vertical leakage; and (c) assumes an area for the basin of roughly 4×10^6 ft^2; the leakage works out to less than 10 gpm. A total volume flux was computed for the UDS at line Z-Z', where heads indicate (Plates 3 and 4) that the UDS could be discharging into the ALL beneath Basin F. This flux was computed to be about 13 gpm. This left a residual of 31 gpm (assuming the Basin F flow regime is in an equilibrium balance) which needed to be crossing line Z-Z' in the ALL. By back solving using this flux and gradients from Plate 3 the ALL permeability in BANA was computed to be 480×10^{-4} cm/sec (1019 gal/day-ft^2). This value was used in all calculations involving the ALL aquifer in BANA.

20. Table 3 summarizes the total flux computations made for the four lines previously mentioned. As had been shown in Reference e, flow out of Basin A is quite low in all three aquifers. An independent calculation here of the flux across line F-F' in the ALL was within a few percent of the flux computed in Reference d. By inspection of Plate 3 it is obvious that all ALL flow across line F-F' should also eventually cross lines Y-Y' and Z-Z'. As can be seen in Table 3, the ALL flux across both of these lines is about two orders of magnitude higher than the present ALL flux out of Basin A. Three possible explanations of this phenomenon are possible:

a. Field permeability, and therefore the flux calculations, are erroneous.

b. There is a great degree of interconnection among the three aquifers, thereby rendering a water balance between Basin A and BANA too complex to compute from the available data control.

c. There are water masses in motion at RMA which reflect different ages, and therefore, different rainfall infiltration and waste disposal rates, thereby rendering a water-balance calculation meaningless due to non-steady-state flow conditions.

The first of these explanations is probably not correct. Preliminary results from the F-North Boundary Study indicate that the slug test results very closely mimic the pump test results in the same area, and, therefore, the slug test results in BANA and Basin A are probably reliable. The second of the explanations is quite feasible, since several areas of interconnectivity among the three aquifers have already been identified from boring logs both in Basin A (Reference e) and in BANA. The third explanation is also feasible since there is already at least prima facie evidence of more than one water mass present in Basin A (Reference e). Probably a combination of the second and third possibilities applies, thereby rendering a mass balance computation for BANA virtually impossible regardless of drilling control.

21. Different water masses in motion is argued for quite powerfully in the ALL by comparison of Table 3 with Plate 3. Plate 3, as contoured, shows a flow net which would not allow much, if any, of the present ALL flow out of Basin A to travel to the north to flow under Basin F. And yet, the northerly flow across line Y-Y' in the ALL is almost 100 times that of the flow in the ALL exiting Basin A. Flow across the westerly ALL channel of line Y-Y' is almost 250 times that of the ALL flow exiting Basin A. Even if all of the flow from all three aquifers across line F-F' were combined with all of the UDS and LDS flow across Y-Y' (analogous to all "bedrock" flow discharging into the alluvium), this total would still account for only 66.4 percent of the ALL flow in the westerly direction across line Y-Y'. Apparently the flow across both segments of line Y-Y' in the ALL represents a "slug" of old water which may have exited Basin A as much as 20 years ago when waste disposal in Basin A kept saturated flow volume high in the ALL.

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WATER QUALITY SURVEY

General

22. Field sampling work for the groundwater quality study was initiated in December 1978. The samples were recovered according to the sampling schedule as given in Reference d, Appendix A. All samples collected in one day were delivered to the Material Analysis Laboratory Division (MALD) for preparation and analysis the same day. The procedures employed in the analysis of these samples can be obtained from RMA.

Methods of Data Analysis

23. All chemical results obtained for the study area were recorded on plan maps. These data were also plotted on geologic cross sections according to the depth from which the samples were recovered (well screen depth). Based on the cross sections, the water quality data were correlated and segregated for the various water-bearing units within the study area. Since the contaminants exiting the Basin A study area were found to be moving in the middle water-bearing unit, the UDS (Reference d), this unit was given primary emphasis in the data analysis. The correlated data was averaged at each well screen location and plotted on plan maps. Thus, these water quality results represent a single picture in time of the distribution of the various contaminants within the study area. These averaged data were contoured and the contaminant distributions were plotted using isoconcentration maps.

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Discussion of Results

24. The geology within the study area is complex, as was indicated earlier. The less permeable clay layers which function as confining beds between the various water-bearing zones were found not to be continuous over the study area. These "windows" in the confining layers provide areas where vertical water movement can occur between the various water-bearing units. While this movement may be small enough so as not to have a noticeable effect on a water balance in the study area, the effect on contaminant distribution over time could be significant. Correlation of water quality data was difficult and numerous data gaps in the control of groundwater movement, as well as water quality, were noted. The four contaminants, chloride ion, oxathiane, diisopropylmethylphosphonate (DIMP), and dithiane identified in Reference d as migrating into the BANA were closely evaluated. These were the only contaminants found in sufficient quantities to merit evaluation. The history of the disposal of these contaminants was discussed in Reference d. The distribution of these contaminants in the UDS is shown in Plates 17 through 20, respectively. The contours close around the Basin C area, although this may be an artifact of lack of sample control under Basin F. The ALL in this area is dry and it is believed that the contaminant concentrations present in the UDS have resulted from vertical movement of groundwater from the ALL to the UDS.

25. Prior to 1957, during the period when Basin A was an active disposal area, there was a head on the groundwater system in the Basin A

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area, probably resulting from disposal activities. This head caused infiltration and groundwater flow at levels above those which would have occurred naturally. In order to accommodate this volume of contaminated groundwater there was significant flow in the ALL. That there was significantly more flow in the ALL then was confirmed by Konikow's 1975 model work. When the Basin A dike was breached the quantity of groundwater infiltration was reduced and the cross sectional area required to carry alluvial flow was also reduced. The "windows" between the ALL and the UDS acted as "drainage points" for the ALL into the UDS. In short, after use of Basin A was suspended, there was not a sufficient quantity of groundwater flow to support both the ALL and the UDS water-bearing units, and the water in the ALL moved vertically to the lower units in adjustment to the new flow quantities. Because of the "windows" between the ALL and UDS these units can in some ways be considered to be one water-bearing unit. If the quantity of groundwater flow in this combined aquifer were reduced, the water table would fall and areas that were once saturated would become desaturated and, eventually, dry.

26. The time for this occurrence over the study area would vary with the distance from the source. The areas closest to the source would be affected first. Thus it is understandable that a relatively definable flow pattern from the ALL to the UDS has been established in the northern part of Basin A between the G-G' well lines and the F-F' well lines (Reference d). As the distance from the source increased, however, the nature and extent of this vertical movement would become less definable.

Further, if groundwater movement rates are slow enough, or if the UDS is not as extensive as the ALL, it would be possible to find high contaminant levels in the ALL. These levels would be representative of the trailing edge of the old pollution plume that was exiting Basin A after its period of active disposal operations. The groundwater and chemistry conditions found in the BANA study area indicate that the above described sequence of events was certainly feasible.

27. After use of Basin A was suspended the driving force and supply of groundwater flow were notably reduced. This effect moved down gradient from Basin A into the BANA. Some contaminants were carried out of Basin A with what may be looked upon as the "last flush" of pollutants from the active disposal site. These pollutants drained to the Basin C area. This "last flush" could have been a combination of both surface water and groundwater flow. If, when the Basin A dike was breached, the contained liquid was allowed to drain to Basin C, and was then pumped into Basin F, some of the wastes temporarily contained in Basin C would have infiltrated to the ALL groundwater system. The driving force to move this water out of the area, however, was decreasing with time, and the contaminants probably moved both vertically and horizontally. Also, during this time, flushout of Basin A was continuing and contaminants were migrating across the F-F' well line into the study area in the UDS. This movement would have been slow, but it did help augment the contaminant levels in the UDS. If the contaminants moving vertically migrated essentially as a "slug" of highly contaminated water into the UDS, a closed contour pattern would be expected. This is the pattern

that has been observed in the study area. Judging by the slow rate of groundwater movement in the study area, approximately 6 cm/day (0.2 ft/day) across the F-F' line, it is feasible that this movement pattern has taken in excess of 20 years to develop, and it may take longer than that to naturally flush the upper water-bearing unit.

28. If the extent of the ALL is greater than the UDS, or if the groundwater movement rate is slow enough, it might be possible to locate the high contaminant levels in the ALL which represent the trailing edge of the contamination plumes from the original Basin A disposal activities. Plate 21 shows the distribution of chloride ion in the ALL. Comparison of Plates 18 and 21 shows that where the UDS chloride plume ends, the ALL plume is continuous with it. Further, comparison of Plates 18 and 21 with Plate 3, depicting the groundwater levels in the ALL, indicates that the contaminant distribution in the UDS matches well with the dry area in the ALL and the contaminant plumes in the ALL also correlate with the groundwater pattern shown.

29. Based on field information, the above scenario appears feasible and is compatible with known historical information as well as the data derived from the Basin A study. However, the above discussion is qualitative. A quantitative analysis will be needed to determine the fluxes and rates of movement of the contaminated flow. Because of the complexity of the BANA hydrogeology, and because placement of the piezometers (800 series borings) is relatively wide spaced, it is considered that the available information is not sufficiently well detailed to allow a strict quantitative analysis. Contaminant flux

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diagrams drawn from the available information would not be considered reliable. The available data is sufficient for a good qualitative analysis, but not for quantification of contaminant movement.

CONCLUSIONS

30. The BANA is probably the area of the RMA with the most complex geology and geohydrology. The high degree of interconnectivity among the three aquifer units demonstrated from only 26 new borings indicates that there is probably insufficient boring control in the BANA to provide definitive stratigraphic control for adequate description of the groundwater flow regime.

31. Water quality monitoring in the BANA also indicates a complex set of interactions among the three aquifers. It would be very desirable to have well screens in many locations where they do not exist now, and further, more new boring sites and well screens would be highly desirable.

32. At present the contribution of contaminated flow from Basin A ALL to the total ALL flow in the BANA is virtually insignificant. It has probably been insignificant for at least several years, and will probably remain so at least until the front from the "mound" in the southern end of Basin A (Reference e) reaches the exit in the neck of Basin A.

33. With heads in the ALL higher than in the UDS, there is a high probability that contaminants in transport in the ALL are being "underdrained" into the UDS. This would make migration in the UDS much more important than heretofore suspected.

34. Chemical contamination has spread from the Basin A area into the Basin C, D, and E area. This contamination is primarily in the UDS with the highest recorded levels in the Basin C area. It appears that this contamination may have migrated vertically from the ALL into the UDS. Rates of vertical movement versus horizontal movement, as well as the complex interrelationship of these two, are not known quantitatively.

35. The LDS showed little contamination in the study area. The deep screens in the Basin C area were the only points where some contaminants were found, but at low levels (for example, DIMP was less than 100 ppb). However, contaminants have migrated to that depth and "windows" between the UDS and LDS have been documented. In general the groundwater heads in the BANA are such that water will move progressively deeper. Thus, if "windows" between water-bearing units are in the contaminated flow path, contamination will move to the deeper water-bearing units. Vertical movement rates are not known, but are probably much slower than horizontal movement rates. Given time it is very probable that the contamination in the UDS could move to the LDS.

RECOMMENDATIONS

36. There are five main data gap areas:

<u>a</u>. Between Basin C and the F-F' well line, where only boring No. 658 exists, it was too shallow and no samples could be recovered.

<u>b</u>. The Basin C area appears to be a "hot spot" for contamination in the UDS and requires more detail to be quantified.

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c. The narrow area between Basin C and Basin F. The existing wells in this area were drilled and screened in the UDS and no data is available about the ALL. These data could be significant to the interpretation and quantification of the interrelationships between the aquifers. Data obtained from these wells may be affected by water from the upper aquifer moving down around the well casing and into the lower screen. The water quality data from these wells all correlated very well for all contaminants at all depths suggesting cross contamination. None of the data could be used. This area is critical because it forms the last line of sampling before groundwater flow moves under Basin F. The lack of reliable sampling points in this area is one of the main reasons a quantitative hydrogeochemical analysis could not be done.

d. West of Basin F. The sampling points in this area are too widely scattered to allow quantitative definition.

e. Along the E-E' well line. These wells are all too shallow. Based on the available data, it appears that the UDS is pinching out in this area, but it may just be a localized pinch-out with isolated exit areas along the E-E' line. Without deeper wells in this area, no definition is possible.

37. Table 4 is a listing of well screens which are recommended to be installed at existing boring sites in order to enhance geochemical

control of the geohydrologic regime in the BANA. Unless rotary drilling services become available sooner, these installations should probably be postponed pending results of the geohydrologic integration study to be accomplished in Quarter 4, FY 79.

38. Table 5 is a listing of new exploratory borings and well screens in the BANA which will fill in data gaps in the geohydrologic and geochemical control presently available. These exploratory borings can be done if auger drilling services become available prior to FY 80. However, they should probably be postponed until after the recommendations of the geohydrologic integration study become available in early FY 80.

39. Inspection and plotting of a number of boring logs and screen emplacements have shown a number of installations which cross connect two or more of the aquifer units at RMA. These screen installations are probably aiding the acceleration of vertical migration of contaminants between aquifers. The only proper way of mitigating this problem is to drill out the offending screens and gravel packs and grout the holes to provide a seal between aquifers. Table 6 is a listing of such wells.

40. The physical significance of the lowest heavy lines in the stratigraphic cross sections (Plates 6-12) may be tested with heavy mineral analyses. If the UDS and LDS are indeed different, then their corresponding heavy numerical assemblages should show some statistically significant differences. If they are genetically related, and the heavy line is indeed a redox boundary, then the heavy mineral suites should be quite similar. Heavy mineral analyses are recommended to be performed on not less than 10 UDS and 10 LDS samples.

41. The ages of water masses may be tested through Tritium-dating of water samples from around the arsenal. Such a dating test is highly recommended.

Table 1: S... of Boring Data, Basin A Neck Area, Rocky Mountain Arsenal.

Boring No.	Drilling Date	Driller and Rig Type	Total Depth (ft)	Depth to Top of Denver Formation (ft)	Elevation of Ground (ft, MSL)	Elevation Top of Denver Formation (ft)	USCS, Top of Denver Formation	Screen Interval (ft)	Aquifer Screened	Elevation Top of Casing (ft, MSL)	Undisturbed Sample Interval (ft)	Mid-Screen Elevation (ft, MSL)	USCS of Screened Interval
801	10 Oct 78	Contract-A	107.4	34.5	5198.7	5164.2	CL	--	--	--	--	--	--
801	9 Nov 78	Taylor-A	39.5	--	--	--	--	27.4-34.5	ALL	5200.5	--	5167.8	GP
801	17 Oct 78	Stewart-R	62.0	--	--	--	--	49.0-57.0	UDS	5200.5	55.0-57.5	5145.7	SM
801	19 Oct 78	Stewart-R	112.0	--	--	--	--	99.0-107.0	LDS	5200.9	105.0-107.4	5095.7	SM
802	12 Oct 78	Contract-A	109.3	30.1	5188.4	5158.3	CL	--	--	--	--	--	--
802	16 Nov 78	Taylor-A	35.1	--	--	--	--	20.1-30.1	ALL	5191.1	--	5163.3	SM
802	20 Oct 78	Stewart-R	84.5	--	--	--	--	67.5-79.5	UDS	5190.3	75.0-76.5 77.5-80.0	5114.9	SM
803	13 Oct 78	Contract-A	104.5	34.0	5199.0	5165.0	ML	--	--	--	--	--	--
803	10 Nov 78	Taylor-A	39.0	--	--	--	--	26.0-34.0	ALL	5201.1	--	5169.0	SP
803	23 Oct 78	Stewart-R	59.0	--	--	--	--	46.0-54.0	UDS	5200.8	50.0-52.5	5149.0	SM
803	24 Oct 78	Stewart-R	109.0	--	--	--	--	92.0-104.0	LDS	5201.1	100.0-101.8	5101.0	SM
804	18 Oct 78	Contract-A	109.8	50.2	5223.0	5172.8	ML	--	--	--	--	--	--
804	15 Nov 78	Taylor-A	55.2	--	--	--	--	46.2-50.2	ALL	5225.7	--	5174.8	SP
804	25 Oct 78	Stewart-R	64.0	--	--	--	--	51.0-59.0	UDS	5224.8	54.0-56.5	5168.0	ML
804	23 Oct 78	Stewart-R	104.5	--	--	--	--	80.5-99.5	LDS	5225.0	*	5129.0	SM
805	19 Oct 78	Contract-A	99.5	32.5	5183.8	5161.3	CH	--	--	--	--	--	--
805	10 Nov 78	Taylor-A	37.5	--	--	--	--	25.4-32.5	ALL	5185.8	--	5154.9	SP
805	30 Oct 78	Stewart-R	89.5	--	--	--	--	72.5-84.5	LDS	5186.4	76.0-78.5	5105.3	SM
806	21 Oct 78	Contract-A	100.0	25.5	5175.1	5149.6	CH	--	--	--	--	--	--
806	13 Nov 78	Taylor-A	30.5	--	--	--	--	21.2-25.5	ALL	5178.0	--	5151.8	SP
806	2 Nov 78	Stewart-R	54.0	--	--	--	--	41.0-49.0	UDS	5177.8	*	5130.1	CL
806	31 Oct 78	Stewart-R	85.0	--	--	--	--	68.0-80.0	LDS	5177.9	74.0-76.5	5101.1	ML
807	26 Oct 78	Contract-A	85.3	27.6	5173.8	5146.2	CL	--	--	--	--	--	--
807	11 Nov 78	Taylor-A	32.6	--	--	--	--	17.9-27.6	ALL	5176.3	--	5151.1	SP
807	8 Nov 78	Stewart-R	77.0	--	--	--	--	60.0-72.0	LDS	5175.8	69.0-71.5	5107.8	SM
808	24 Oct 78	Contract-A	89.7	20.5	5172.8	5152.3	SM	--	--	--	--	--	--
808	6 Nov 78	Taylor-A	32.0	--	--	--	--	17.0-27.0	ALL/UDS	5175.1	--	5150.8	SP/SM
808	7 Nov 78	Stewart-R	87.0	--	--	--	--	70.0-82.0	LDS	5174.7	79.0-81.2	5096.8	SM
809	17 Nov 78	Taylor-A	99.2	32.1	5210.5	5178.4	ML	--	--	--	--	--	--
809	20 Nov 78	Taylor-A	37.1	--	--	--	--	22.9-32.1	ALL	5212.4	--	5183.0	SP
809	21 Nov 78	Stewart-R	89.0	--	--	--	--	64.0-84.0	UDS/LDS	5212.3	55.0-57.5 75.0-77.5	5136.5	SM/SM
810	27 Oct 78	Contract-A	74.8	35.0	5187.3	5152.3	ML	--	--	--	--	--	--
810	11 Nov 78	Taylor-A	40.0	--	--	--	--	27.7-35.0	ALL/UDS	5189.55	--	5156.0	SP/ML
811	1 Nov 78	Contract-A	84.5	43.5	5167.9	5124.4	CH	--	--	--	--	--	--
811	13 Nov 78	Taylor-A	40.2	--	--	--	--	25.2-35.2	ALL	5170.5	--	5137.7	SP
812	30 Oct 78	Contract-A	89.6	36.0	5172.0	5136.0	CH	--	--	--	--	--	--
812	13 Nov 78	Taylor-A	41.0	--	--	--	--	32.0-36.0	ALL	5174.7	--	5138.0	SP
812	3 Nov 78	Stewart-R	74.0	--	--	--	--	57.0-69.0	UDS	5173.0	55.0-57.5	5109.0	SM
812	4 Nov 78	Stewart-R	89.0	--	--	--	--	76.0-84.0	LDS	5173.3	79.0-81.5	5092.0	SM
813	16 Nov 78	Contract-A	95.0	42.0	5168.3	5126.3	SM	--	--	--	--	--	--
813	18 Nov 78	Taylor-A	58.8	--	--	--	--	33.8-53.8	ALL/UDS	5169.9	--	5124.5	SP/SM
814	14 Nov 78	Contract-A	99.9	26.7	5179.4	5152.7	CH	--	--	--	--	--	--
814	17 Nov 78	Taylor-A	31.9	--	--	--	--	17.7-26.9	ALL	5182.2	--	5157.1	CL
814	20 Nov 78	Stewart-R	88.0	--	--	--	--	63.0-83.0	UDS	5181.3	50.0-52.5 70.0-70.9	5106.4	SM
815	13 Nov 78	Contract-A	99.0	20.7	5183.0	5162.3	ML	--	--	--	--	--	--
815	17 Nov 78	Taylor-A	25.7	--	--	--	--	10.7-20.7	ALL	5184.6	--	5167.3	SP

(Continued)

* Undisturbed sample attempted three times--no sample recovered.

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Table 1: (Continued)

Boring No.	Drilling Date	Driller and Rig Type	Total Depth (ft)	Depth to Top of Denver Formation (ft)	Elevation of Ground (ft, MSL)	Elevation Top of Denver Formation (ft)	USCS, Top of Denver Formation	Screen Interval (ft)	Aquifer Screened	Elevation Top of Casing (ft, MSL)	Undisturbed Sample Interval (ft)	Mid-Screen Elevation (ft, MSL)	USCS of Screened Interval
815	17 Nov 78	Stewart-R	96.0	--	--	--	--	71.0-91.0	UDS	5184.8	75.0-77.5	5102.0	SM
816	6 Nov 78	Contract-A	119.6	25.0	5200.1	5175.1	CL	--	--	--	--	--	--
816	17 Nov 78	Taylor-A	30.0	--	--	--	--	15.0-25.0	ALL	5201.9	--	5180.1	SP
816	16 Nov 78	Stewart-R	84.0	--	--	--	--	59.0-79.0	UDS	5202.2	60.0-62.3	5131.1	SM
816	14 Nov 78	Stewart-R	117.0	--	--	--	--	104.0-112.0	LDS	5201.6	109.0-110.6	5092.0	SM
817	9 Nov 78	Contract-A	104.3	17.0	5207.0	5190.0	CH	--	--	--	--	--	--
817	14 Nov 78	Taylor-A	23.2	--	--	--	--	10.0-18.2	ALL	5210.3	--	5192.9	SP
817	24 Nov 78	Stewart-R	53.0	--	--	--	--	28.0-48.0	UDS	5207.9	35.0-36.3	5169.0	SM
817	22 Nov 78	Stewart-R	94.0	--	--	--	--	74.0-89.0	LDS	5208.3	80.0-81.9	5125.5	SM
818	2 Nov 78	Contract-A	119.6	36.0	5202.5	5166.5	CH	--	--	--	--	--	--
818	14 Nov 78	Taylor-A	44.1	--	--	--	--	30.0-39.1	ALL	5204.2	--	5168.0	SP
818	10 Nov 78	Stewart-R	72.0	--	--	--	--	59.0-67.0	UDS	5204.4	62.0-64.5	5139.5	SM
818	13 Nov 78	Stewart-R	117.0	--	--	--	--	100.0-112.0	LDS	5204.2	100.0-102.5 110.0-112.4	5096.5	SM
819	22 Nov 78	Taylor-A	109.0	27.6	5191.3	5163.7	CH	--	--	--	--	--	--
819	23 Nov 78	Taylor-A	33.0	--	--	--	--	18.0-28.0	ALL	5193.0	--	5168.3	SP
819	25 Nov 78	Stewart-R	107.0	--	--	--	--	82.0-102.0	LDS	5193.2	90.0-92.5	5099.3	SM
820	25 Nov 78	Taylor-A	100.5	56.0	5175.5	5119.5	CH	--	--	--	--	--	--
820	26 Nov 78	Taylor-A	61.0	--	--	--	--	46.0-56.0	ALL	5177.5	--	5124.5	SP
821	1 Dec 78	Taylor-A	95.5	20.4	5186.8	5166.4	CH	--	--	--	--	--	--
821	22 Dec 78	Heick-A	25.5	--	--	--	--	15.5-20.5	ALL	5189.1	--	5169.1	SP
822	2 Dec 78	Taylor-A	115.5	34.2	5200.2	5166.0	CH	--	--	--	--	--	--
822	12 Dec 78	Heick-A	40.0	--	--	--	--	27.0-35.0	ALL	5202.8	--	5168.8	SP
823	30 Nov 78	Heick-A	81.5	33.0	5213.9	5180.9	ML	--	--	--	--	--	--
823	2 Dec 78	Heick-A	38.0	--	--	--	--	25.0-33.0	ALL	5216.6	--	5184.9	SP
823	30 Nov 78	Stewart-R	70.0	--	--	--	--	45.0-65.0	UDS/LDS	5215.3	50.0-52.5 60.0-62.5	5158.9	SM/SM
824	6 Dec 78	Taylor-A	85.5	24.0	5208.3	--	SM	--	--	--	--	--	--
824	30 Apr 78	Heick-A	29.0	--	--	--	--	20.0-24.0	ALL/UDS	5210.2	--	5186.3	SP/SM
824	10 Apr 79	Warhurst-R	76.2	--	--	--	--	61.2-71.2	UDS	5210.6	*	5142.1	SM
825	16 Apr 79	Warhurst-R	104.5	46.5	5220.9	5174.5	CH	78.0-98.0	UDS/LDS	5223.2	*	5132.9	SM/SM
825	1 May 79	Heick-A	51.5	--	--	--	--	42.5-46.5	ALL	5223.2	--	5176.4	SP
826	20 Apr 79	Heick-A	96.5	24.8	5257.3	5222.5	CL	--	--	--	--	--	--
827	18 Apr 79	Heick-A	101.5	38.0	5197.1	5159.1	CH	--	--	--	--	--	--
827	18 Apr 79	Warhurst-R	80.0	--	--	--	--	65.0-75.0	LDS	5199.9	*	5127.1	SM
651**	3 Nov 78	Taylor-A	90.5	15.5	5225.9	5210.4	CH	--	--	--	--	--	--
651**	4 Nov 78	Taylor-A	55.0	--	--	--	--	46.6-50.0	UDS	5228.4	--	5177.6	ML
651**	15 Nov 78	Stewart-R	81.0	--		--	--	59.0-76.0	LDS	5228.4	70.0-72.5	5158.4	SM
640**	28 Nov 78	Stewart-R	72.0	--	5240.6	--	CH	57.0-67.0	UDS	5242.3	*	5178.6	SM
455**	6 Dec 78	Stewart-R	78.0	--	5203.8	--	ML	63.0-73.0	UDS	5206.9	*	5135.8	SM
455**	5 Dec 78	Stewart-R	105.0	--	--	--	--	90.0-100.0	LDS	5205.7	95.0-97.5	5108.8	SM

* No undisturbed samples taken.
** Redrill of previously drilled boring.

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Table 2: Summary of Permeability Data, Basin A Neck Area, Rocky Mountain Arsenal.

Boring No.	Type of Test*	Analytical Method**	Aquifer Screened***	K (cm/sec) (x 10^{-4})	K (ft/day)	K (gal/day/ft^2)
723	SLUG	C	UDS	9.850	2.79	20.88
723	SLUG	C	LDS	0.137	0.04	0.29
724	FHT	C	UDS	4.150	1.18	8.80
724	SLUG	C	LDS	19.500	5.53	41.13
725	FHT	C	ALL	1.600	0.45	3.39
725	SLUG	C	LDS	5.460	1.55	11.58
455	SLUG	C	UDS	12.150	3.44	25.76
455	SLUG	C	LDS	18.320	5.19	38.84
493	SLUG	C	UDS	22.430	6.36	47.56
493	SLUG	C	LDS	0.013	0.01	0.03
496†	SLUG	C	UDS	71.200	20.18	150.96
496	SLUG	C	LDS	19.360	5.49	41.05
801	SLUG	C	UDS	3.497	0.99	7.41
801	SLUG	C	LDS	7.238	2.05	15.35
802	SLUG	C	UDS	7.281	2.06	15.44
803	FHT	B&R	ALL	1.134	0.32	2.40
803	SLUG	C	UDS	11.530	3.27	24.45
803	SLUG	C	LDS	19.030	5.39	40.35
804	FHT	B&R	ALL	41.990	11.90	89.03
804	SLUG	C	LDS	7.232	2.05	15.33
806	SLUG	C	LDS	0.202	0.06	0.43
807	FHT	B&R	ALL	2.277	0.65	4.83
808	FHT	C	ALL	2.441	0.69	5.18
809	FHT	C	ALL	9.735	2.76	20.64
809	SLUG	C	LDS	6.766	1.92	14.35
810	FHT	C	ALL	5.986	1.70	12.69
812	FHT	B&R	ALL	0.438	0.12	0.93
812	SLUG	C	UDS	22.800	6.46	48.34
812	SLUG	C	LDS	21.320	6.04	45.20
814	SLUG	C	UDS	5.509	1.56	11.68
815	FHT	B&R	ALL	0.083	0.02	0.18
815	SLUG	C	UDS	3.866	1.10	8.20
816	SLUG	C	UDS	7.733	2.19	16.40
817	SLUG	C	LDS	3.495	0.99	7.41
818	SLUG	C	UDS	2.450	0.69	5.19
818	SLUG	C	LDS	1.289	0.37	2.73
819	SLUG	C	LDS	1.297	0.37	2.75
822	FHT	C	ALL	11.900	3.37	25.23
823	FHT	B&R	LDS	1.571	0.45	3.33

* Slug = Slug Test or "Rising Head Test," FHT = Falling Head Test.
** C = Cooper, et al., assumptions, B&R = Bouwer and Rice assumptions.
*** ALL = Alluvium, UDS = upper Denver sand; LDS = lower Denver sand.
† Bad test since water level was within gravel pack.

Table 3: Summary of Total Flux Determinations.

Section Line	Aquifer	Saturated Cross Sectional Area (ft^2)	Range of K (gpd/ft^2)	Range of i (ft/ft)	Flux (gpd)
F-F'	ALL	8,494	3.4*	0.014-0.020	504
F-F'	UDS	26,736	20.9*	0.016-0.026	12,096
F-F'	LDS	39,600	11.6-41.3	0.006-0.028	15,984
Y-Y'	ALL (West)	11,683	1019**	0.019-0.024	121,968
Y-Y'	ALL (North)	2,710	1019**	0.013-0.018	45,072
Y-Y'	UDS	134,580	5.1-25.8	0.010-0.020	30,096
Y-Y'	LDS	113,220	2.7-38.8	0.011-0.015	22,320
Z-Z'	ALL	6,140	1019**	0.005-0.020	45,072
Z-Z'	UDS	41,609	25.0-48.0	0.010-0.011	18,576
Z-Z'	LDS	65,075	10.0-40.0	0.004-0.011	17,280
9th Avenue	ALL	16,840	7000***	0.0006-0.001	70,704

* Only value available.
** Back-calculated value.
*** Pump Test value, Boring No. 368.

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Table 4: Recommended Additional Well-Screen Emplacement, Basin A Neck Area.

Boring No.	Cross Section Line	Screen Length (ft)	Aquifer Screened	Material Screened	Bottom of Screen* (ft)
657**	F-F'	8	LDS	SM	94.0
655**	F-F'	8	LDS	SM	86.0
653	F-F'	8	SDS	SM	80.0
653	F-F'	4	ALL	SP	32.0
650	F-F'	4	ALL	SM	34.0
649	F-F'	4	ALL	SM	36.0
648	F-F'	4	ALL	SM	31.0
647	F-F'	4	UDS	SM	49.0
644***	F-F'	8	LDS	SM	121.0
139**	U-U'	12	UDS	SM	59.0
139	U-U'	12	LDS	SM	102.0
80**	U-U'	8	LDS	SM	108.0
723	V-V'/F-F'	8	UDS	SM	60.0
141**	V-V'	8	UDS	SM	60.0
141	V-V'	12	LDS	SM	97.0
675**	V-V'	8	UDS/LDS	SM	100.0
813	V-V'	12	LDS	SM	91.0
635**	V-V'/E-E'	12	LDS	SM	91.0
673	W-W'	8	ALL	SP	36.0
674**	W-W'	8	LDS	SM	78.0
674	W-W'	8	ALL/UDS	SP/ML	24.0
771	X-X'	8	LDS	SM	94.0
770	X-X'	24	UDS/LDS	SM	77.0
658	X-X'	8	UDS	SM	61.0
658	X-X'	12	LDS	SM	99.0
488**	X-X'	8	LDS	SM	75.0
42	X-X'	16	ALL/UDS	SP/SC	48.0

(Continued)

* All depths are from top of ground (TOG), MSL Datum.
** Redrill exploratory boring to 110 ft first to confirm screen interval.
*** Redrill exploratory boring to 130 ft first to confirm screen interval.

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Table 4: (Continued)

Boring No.	Cross Section Line	Screen Length (ft)	Aquifer Screened	Material Screened	Bottom of Screen* (ft)
617**	X-X'/E-E'	8	LDS	SM	70.0
876	Y-Y'	4	ALL	SP	42.0
876	Y-Y'	8	UDS	SM	69.0
491***	Y-Y'	12	LDS	SM	124.0
490***	Y-Y'	12	LDS	SM	110.0
822	Y-Y'	12	LDS	SM	119.0
130***	Z-Z'	12	LDS	SM	122.0
492***	Z-Z'	12	LDS	SM	103.0
492†	Z-Z'	12	UDS	SM	78.0
492	Z-Z'	8	ALL	SM/SP	37.0
776	F_1-F_1'	16	UDS	SM	43.5
776	F_1-F_1'	8	LDS	SM	91.0
774	F_1-F_1'	8	LDS	SM	63.0
772	F_1-F_1'	8	ALL	SM/SP	39.0
770**	F_1-F_1'	12	LDS	SM	76.0
771	F_2-F_2'	8	LDS	SM	70.0
773	F_2-F_2'	4	ALL	SP	48.0
773	F_2-F_2'	8	LDS	SM	68.0
775	F_2-F_2'	8	LDS	SM	70.0
732	G-G'	4	UDS	SM	36.0
726†	G-G'	8	ALL	SM	41.0
726	G-G'	8	LDS	SM	88.0
734	G-G'	8	LDS	SM	88.0

* All depths are from top of ground (TOG), MSL Datu.
** Redrill exploratory boring to 110 ft first to confirm screen interval.
*** Redrill exploratory boring to 130 ft first to confirm screen interval.
† No trap should be used.

WORKING DRAFT

Table 5: Recommended New Exploratory Borings, Basin A Neck Area.

Boring No.	Section	Northing	Easting	Depth (ft)	Probable No. of Screens
X-1	25	190,610	2,186,290	130	2
X-2	25	190,480	2,185,610	130	2
X-3	25	190,450	2,184,910	130	2
X-4	25	190,330	2,187,210	130	2
X-5	25	189,800	2,185,730	130	2
X-6	25	189,790	2,184,900	130	2
X-7	25	189,610	2,186,900	130	2
X-8	25	188,660	2,187,200	130	2
X-9	25	188,700	2,185,880	130	2
X-10	25	188,860	2,184,900	130	2
X-11	25	189,370	2,183,670	100	2
X-12	25	188,580	2,183,670	100	2
X-13	25	187,950	2,187,450	100	2
X-14	25	187,860	2,186,100	130	2
X-15	25	187,050	2,187,520	100	2
X-16	25	187,040	2,186,230	130	2
X-17	25	186,350	2,186,350	130	2
X-18	25	186,580	2,185,060	130	2
X-19	25	187,210	2,184,550	130	2
X-20	25	187,280	2,183,660	110	2
X-21	25	186,520	2,183,720	110	2
X-22	26	189,740	2,183,090	100	2
X-23	26	189,720	2,182,390	100	2
X-24	26	189,260	2,182,700	100	2
X-25	26	188,600	2,182,720	110	2
X-26	26	187,540	2,182,640	130	3
X-27	26	188,050	2,182,290	110	3
X-28	26	187,580	2,181,390	110	2
X-29	26	186,840	2,181,950	130	3

WORKING DRAFT

Table 5: (Continued)

Boring No.	Section	Northing	Easting	Depth (ft)	Probable No. of Screens
X-30	26	186,950	2,181,130	110	2
X-31	26	186,480	2,181,550	110	2
X-32	26	187,750	2,180,490	110	3
X-33	26	186,610	2,180,630	110	3
X-34	26	186,580	2,180,050	110	3
X-35	26	187,040	2,180,060	110	3
X-36	26	188,560	2,179,470	110	2
X-37	26	187,960	2,179,360	110	2
X-38	26	188,980	2,178,380	110	2
X-39	26	187,790	2,178,750	110	2
X-40	26	186,770	2,179,140	110	2
X-41	26	187,660	2,178,000	110	2
X-42	26	186,080	2,177,370	110	3
X-43	26	185,940	2,181,370	110	3
X-44	26	185,450	2,181,200	110	3
X-45	26	185,070	2,181,400	110	3
X-46	26	184,460	2,180,320	130	3
X-47	35	184,060	2,181,580	130	3
X-48	26	189,190	2,179,000	110	2

WORKING DRAFT

Table 6: Well Screens Recommended for Drilling Out and Grouting Up.

Well No.	Section	Aquifer Screened	Trap Bottom (ft)	Screen Bottom (ft)	Depth Drilled (ft)
438	26	ALL	80.0	41.9	80.0
455	26	ALL	89.4	41.1	89.4
461	26	ALL	81.4	47.4	81.4
405	26	ALL	90.0	47.0	90.0
419	26	ALL	89.8	47.5	89.9
423	26	UDS	61.5	59.6	74.0
880* (ESA)	26	UDS	60.0	55.0	60.0

* Boring on Skimmer Pond Weir, southeast corner Basin F. Well screen never properly installed or backfilled. If possible pipe should be removed, hole redrilled open, screen reset with interval at 45.0-55.0, and proper grouting procedures followed. Gravel pack no shallower than 40.0 ft.

WORKING DRAFT